The humidity at 8 a. m., figures 5 and 6, presents curious variations. Although 60 per cent of September days, the highest number of any month, are without rain, yet 15 per cent of the days, the highest number of any month, have a humidity at 8 a. m., *two hours after sunrise,* of 98 to 100 per cent. This is due to the prevalence of fogs in that month, the fogs, in turn, being caused by the prevalence of clear nights with diminished temperature. (Fig. 7.) The modal period for dense fog is September 8 to 17. The humidity then diminishes to November, the "Indian summer" month, and increases again with the formation of snow cover in December. It is rather surprising to find the mode for 8 a. m. humidity in January and February to be 98 to 100 per cent. The high humidity occurs on mornings of "radiation" cold and is often accompanied by rime and fog. It is unfortunate that data of daily maximum and minimum humidity are not available.

The smooth curve marked by the tops of the columns of no precipitation, figures 5 and 6, is interesting, as is also the variation in the number of days with a trace. In summer traces of precipitation tend to evaporate before they reach the ground. In winter traces are prominent in the form of snow flurries. The curve of days with no precipitation shows inverse relation to that of days with 10 tenths clouds, or sky entirely overcast, figures 3 and 4. A peculiar feature of the latter is that any decrease in the number of overcast days is divided rather evenly among the days with lesser amounts of cloudiness, the number of entirely clear days remaining fairly constant throughout the year, though greatest in September. Since 1905, or for 15 years of the 29, the daily amount of cloudiness has been determined by observations every two hours of the amount, kind, and direction of movement of the clouds.

Figure 7 shows the annual distribution of the different daily weather elements. The two modes of maximum, minimum, and mean temperature are due to the fact that there is rather rapid transition from summer to winter and vice versa. When monthly means are used, instead of daily, a third mode due to spring and fall appears, but this is only a feature of the method of computation and daily data should be used in place of monthly when practicable. The dual mode in the range of monthly maximum temperature is probably a snow cover and humidity effect. The dominant mode, 32°, corresponds to the mode for monthly range of minimum temperature, 31°.

Figure 8 shows how histograms of monthly temperature and precipitation, which are very easily prepared from the station annual summaries, although of different nature from histograms made with the daily data, are useful in comparing climates with respect to the general features of rainfall and temperature.

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TEMPERATURE VARIATIONS IN THE UNITED STATES AND ELSEWHERE.

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[Weather Bureau, Washington, D. C., February, 1921.]

SYNOPSIS.

In the first part of the paper effort is made to discover to what extent periods of abnormally high or abnormally low temperature in the United States synchronize and also as to whether or not there is evidence of a periodicity in the occurrence and recurrence of these phenomena. The basic material for the study was 12-month consecutive or overlapping monthly means of the temperature for fairly large geographic districts. The districts used are (1) the New England States, (2) Minnesota, (3) Colorado, (4) Washington, and (5) Louisiana. The monthly mean temperature for each of these districts was originally computed from the means of all of the individual stations therein. The period 1888–1919 furnished the data for the study.

As was to have been expected, the control of the changes in temperature of the various parts of the United States is clearly that of the general circulation of the atmosphere, as modified, of course, by the secondary circulation due to the movement of cyclones and anticyclones.

In order to get beyond the influence of the latter the study was extended to include certain tropical stations, viz, Batavia, Habana, Honolulu, and Arequipa. Consecutive means were also computed for these stations.

Both tropical and temperate zone stations show very clearly the persistence of short-period variations of about 40 months in length; occasionally, for reasons not understood, some of these short-period maxima and minima are greatly intensified and consequently appear as primary maxima or minima in the series. The length of the interval between these so-called primary maxima and minima is greater than and probably some multiple of the 40-month period.

One of the chief characteristics of the data is the tendency of any marked variation in the temperature to be followed by another one of

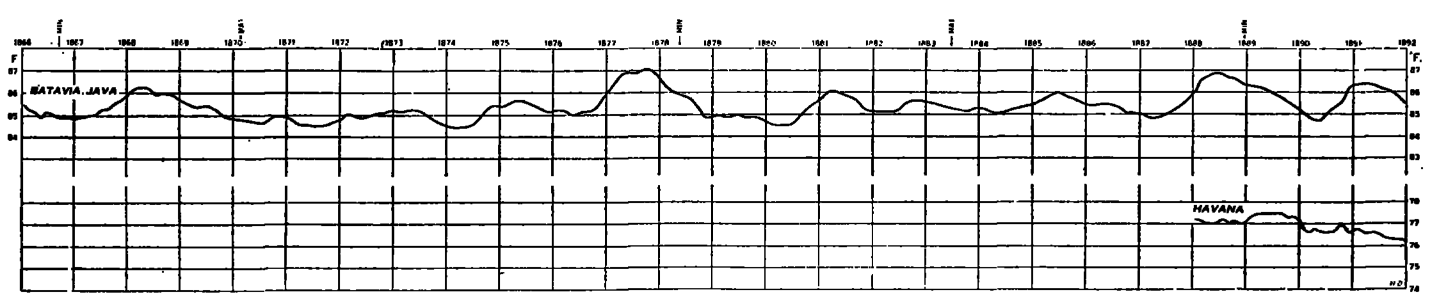


FIG. 1.—Smoothed temperature means, each

opposite phase almost immediately. While this tendency amounts to almost certainty it is useless for forecast purposes because there is no means of discovering the precise duration of any existing phase. A comparison of the temperature variations in the border region between tropics and subtropics led to the conclusion that the influence of the general circulation at times extends to the northern portion of tropical areas. There also seems to be in operation at times a common temperature control for both Tropics and temperate zones. Extracts from the Reseau Mondial for 1910, 1911, and 1912 are quoted in support of this view.

The literature of the sun spot-terrestrial temperature relation is very briefly touched upon and the difficulty of separating the terrestrial from the extra-terrestrial influences is discussed. The annual temperature variations of the United States as a single geographic unit is compared with the sun-spot curve and the resemblances and differences are discussed.

The object of this paper is to discover, if possible, the nature and character of recurring periods of high and low temperature in the United States and elsewhere.

It is well known that in the temperate zones, and even in the Tropics irregular variations in the temperature of the lower layers of the atmosphere take place from time to time. The amplitude of these variations is greater in some years than in others. When it is small, the mean annual temperature is practically a constant and it may so continue for a number of years; then, suddenly, it would seem, the amplitude increases and the irregularities persist for a term of years, after which there is a return to quiescent conditions. It is also generally known that these irregularities, or abnormalities, occur almost synchronously over widely separated parts of the globe. Short-period variations of this character are definitely known to be the result of the movement of cyclones and anticyclones. The influence of the movement of a single cyclonic system upon the air temperature in its path—an influence which will be hereafter referred to as that of the secondary circulation—is clear-cut and easily determined, but when we attempt to integrate this influence over a period of several weeks the task becomes increasingly difficult, unless, as rarely happens, the secondary circulation has been uniform over the entire period. If we take any month of the cold season in the United States with consistently positive or negative temperature anomalies, the reason therefor can generally be referred back to the secondary circulation. There are months, however, when the network of cyclonic paths is so intricate as to preclude the formation of any logical conclusion as to the temperature distribution. In any event a quantitative statement of the influence of the secondary circulation seems to be impossible of ascertainment. A common method of approaching the question is to plot on coordinate paper the variations of both the temperature and the suspected cause thereof and draw free-hand curves through the plotted data in order to note the degree of parallelism between the two events.

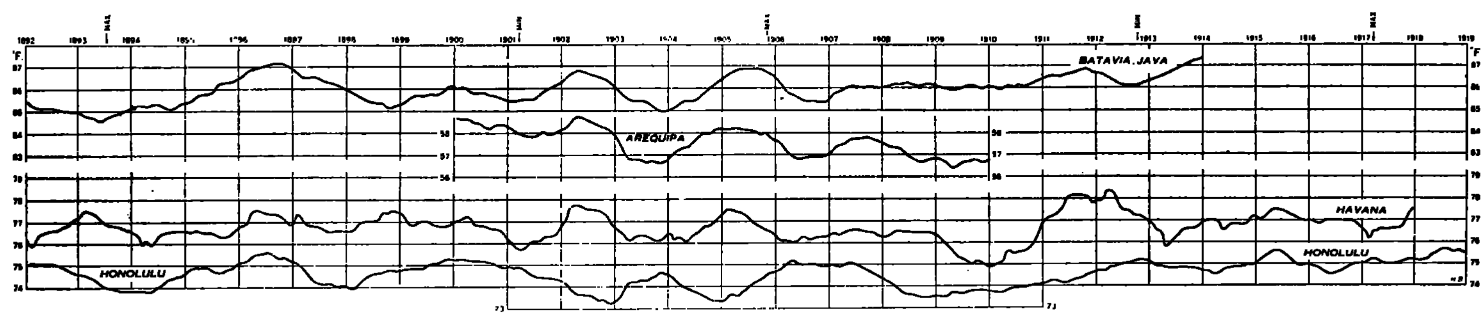
While, in general, there is more or less parallelism between the two curves, yet, on the other hand, many contradictions are also present.

THE MATERIAL USED.

It is proposed in what follows to determine the variations in the annual mean temperature not from the annual means for individual stations, but by the use of 12-month consecutive means for a few geographic districts in the United States. The districts selected are: (1) The New England States, (2) Minnesota, (3) Colorado, (4) Washington, and (5) Louisiana. The first of these is representative of the Atlantic Coast States above 40° N. latitude, the second of the continental interior along the northern border, the third that of the elevated Rocky Mountain region, the fourth that of the Pacific Coast States above 45° N. latitude, and the last of the low latitude portion of the United States along the Gulf of Mexico. Twelve-month consecutive temperature means have been used by Clayton,[1] and especially by Arctowski,[2] in his numerous papers upon temperature distribution.

The advantage in using these means is in the fact that they enable us to discover the succession of warmer and colder periods that might be wholly eliminated by using the mean of the 12 calendar months. In computing 12-month consecutive means I have called the mean of the 12 calendar months the mean for July, then dropping from the sum of the 12 calendar months the mean for the first of the calendar months, January, and adding the mean of the first calendar month of the immediately succeeding year, January, a new sum was obtained, which divided by 12 gave a mean for August, and so on.

While consecutive means for groups of stations have been computed as above indicated, I have been obliged to use the means of individual stations for the Tropics. I have computed the consecutive means for four stations, viz, Batavia, Java, for which fortunately there are available monthly means of the maximum temperature for each month of the period 1866 to 1914. The monthly means of temperature published in the Yearbooks of the Belen College Observatory of Habana, Cuba, were used for that station. The series of observations maintained at Arequipa, Peru, by Harvard College Astronomical Observatory, although covering but a short term of years, gave satisfactory mean values for that station, and finally the monthly mean temperature as observed by the Weather Bureau and cooperative observers at Honolulu, Hawaii, formed the last of the series of tropical stations. Obviously any attempt to consider the temperature variations of the globe as a unit, even on a very limited scale, must take cognizance of the variations in the Tropics. I next plotted the consecutive means for each of the four stations named as abscissae against time as ordinates to form the four curves of figure 1.



value being the mean of 12 consecutive months.

REMARKS ON THE CURVES.

The Tropics—Batavia.—The curve for this station shows very clearly the occurrence of progressive warming

[1] Amer. Meteor. Jour., vol. 1, p. 130.

[2] Changes in Temperature Distribution, Annals N. Y. Acad. Sci., Vol. XXIV, 39-113.

and cooling throughout the entire term of observations—48 years. In order to study these short periodic oscillations, I have formed a table giving for each station the numerical values of the maxima and minima of temperature for the periods indicated by consecutive numbers, 1, 2, 3, etc. (see Table 1 for tropical stations and Table 1a for stations outside the Tropics). This tabulation shows that at Batavia there were 13 cases of pronounced warming in the 48 years. The average interval between the epochs of maxima was 49 months; between minima, 37 months, counting in each case from maximum to maximum and from minimum to minimum. Treating the remaining three stations similarly, it is found that the average interval maximum to maximum is as follows: Habana, 45 months; Arequipa, 31 months; Honolulu, 48 months. The average interval minimum to minimum is Batavia, 37 months; Habana, 31 months; Arequipa, 31 months; and Honolulu, 48 months.

TABLE 1.

MAXIMUM.

Batavia, Java, 1866-1914.

No.	°F.	Date.	Interval. y.	m.
1	86.2	December, 1868	—	—
2	85.7	November, 1875	6	11
3	87.1	March, 1878	2	4
4	86.0	September, 1881	3	6
5	86.0	December, 1885	4	3
6	86.8	December, 1888	3	0
7	86.4	September, 1891	2	9
8	87.2	March, 1897	5	6
9	86.2	June, 1900	6	9
10	86.9	October, 1902	2	4
11	86.9	January, 1906	3	3
12	86.8	April, 1912	6	3
13	87.5	July, 1914	2	3
		Mean	4	1

Habana, Cuba, 1888-1918.

No.	°F.	Date.	Interval. y.	m.
1	77.5	September, 1889	—	—
2	77.5	August, 1893	3	11
3	77.5	October, 1896	3	2
4	77.5	May, 1899	2	7
5	77.7	September, 1902	3	4
6	77.5	August, 1905	2	11
7	78.3	September, 1912	7	1
8	77.5	November, 1915	3	3
			3	9

Arequipa, Peru, 1900-1910.

No.	°F.	Date.	Interval. y.	m.
1	58.7	July, 1900	—	—
2	58.8	October, 1902	2	3
3	58.4	December, 1905	3	2
4	57.8	March, 1908	2	3
			2	7

Honolulu, Hawaii, 1892-1919.

No.	°F.	Date.	Interval. y.	m.
1	75.1	October, 1892		
2	75.6	January, 1897	4	3
3	75.3	May, 1900	3	4
4	74.7	May, 1904	4	0
5	75.2	October, 1906	2	5
6	75.1	November, 1907	1	1
7	75.2	April, 1913	5	5
8	75.7	October, 1915	2	6
9	75.6	January, 1919	3	3
			3	3

MINIMUM.

Batavia, Java, 1866-1914.

No.	°F.	Date.	Interval. y.	m.
1	84.8	July, 1867		
2	84.4	March, 1872	4	9
3	84.4	November, 1874	2	8
4	85.0	November, 1876	2	0
5	84.5	August, 1880	3	9
6	84.8	September, 1882	2	1
7	85.0	March, 1884	1	6
8	85.0	June, 1887	3	3
9	84.8	November, 1890	3	5
10	84.5	December, 1893	3	1
11	85.1	April, 1899	5	4
12	85.5	August, 1901	2	4
13	85.1	May, 1904	2	9
14	85.4	January, 1907	3	4
		Mean	3	1

Habana, Cuba, 1888-1918.

No.	°F.	Date.	Interval. y.	m.
1	76.6	August, 1890		
2	75.9	August, 1892	2	0
3	75.9	November, 1894	2	3
4	76.3	February, 1896	1	3
5	76.5	July, 1898	2	5
6	75.7	September, 1901	3	2
7	76.1	October, 1903	2	1
8	76.1	July, 1906	2	9
9	74.8	June, 1910	3	11
10	75.7	October, 1913	3	4
11	76.1	August, 1917	3	10
			2	7

Arequipa, Peru, 1900-1910.

No.	°F.	Date.	Interval. y.	m.
1	57.9	October, 1901		
2	56.7	February, 1904	2	4
3	56.8	December, 1906	2	10
4	56.3	October, 1909	2	10
			2	7

Honolulu, Hawaii, 1892-1919.

No.	°F.	Date.	Interval. y.	m.
1	73.8	May, 1894		
2	74.7	January, 1896	1	8
3	73.9	August, 1898	2	7
4	73.3	March, 1903	4	7
5	73.3	May, 1905	2	2
6	73.5	April, 1909	3	11
7	74.5	September, 1914	5	5
8	74.5	November, 1916	7	7
			4	0

TABLE 1A.

MAXIMUM.

Louisiana, 1888-1919.

No.	°F.	Date.	Interval. Y.	M.
1	69.3	June, 1890	—	—
2	68.2	November, 1893	3	5
3	68.4	October, 1896	2	11
4	68.5	August, 1897	0	10
5	67.5	August, 1900	3	0
6	67.7	September, 1902	2	1
7	69.6	October, 1906	4	1
8	69.7	May, 1911	4	7
9	68.7	October, 1915	4	5
10	68.3	August, 1918	2	10
		Mean	3	2

Colorado, 1888-1919.

No.	°F.	Date.	Interval. Y.	M.
1	47.5	June, 1890	—	—
2	46.2	June, 1894	4	0
3	46.5	July, 1896	2	1
4	47.4	July, 1900	4	0
5	47.6	November, 1901	1	4
6	46.1	October, 1903	1	11
7	46.4	October, 1906	3	0
8	47.2	September, 1910	3	11
9	45.3	July, 1914	3	10
10	45.4	March, 1916	1	8
11	45.8	May, 1918	2	2
			2	9

Minnesota, 1888-1919.

No.	°F.	Date.	Interval. Y.	M.
1	38.4	August, 1888	—	—
2	43.3	July, 1894	4	1
3	43.5	March, 1898	3	8
4	45.0	May, 1900	2	2
5	44.6	May, 1901	1	0
6	43.2	September, 1905	4	4
7	41.9	June, 1908	2	9
8	41.4	September, 1910	2	3
9	38.1	November, 1914	4	2
10	38.7	April, 1919	4	5
			3	2

New England, 1888-1919.

No.	°F.	Date.	Interval. Y.	M.
1	48.4	September, 1889	—	—
2	47.5	January, 1892	2	4
3	46.8	April, 1894	2	3
4	47.3	May, 1898	4	1
5	47.1	June, 1901	2	1
6	47.2	November, 1902	2	5
7	46.9	June, 1906	4	0
8	47.2	September, 1908	2	3
9	47.2	May, 1910	1	8
10	48.0	June, 1913	3	1
11	47.0	July, 1915	2	1
12	47.1	February, 1919	3	7
			2	9

MINIMUM.

Louisiana, 1888-1919.

No.	°F.	Date.	Interval. Y.	M.
1	65.7	June, 1889	—	—
2	65.6	October, 1891	2	4
3	65.3	December, 1894	3	2
4	65.0	October, 1898	3	10
5	65.3	September, 1901	2	11
6	65.2	March, 1904	2	6
7	65.5	October, 1904	0	6
8	66.7	June, 1910	5	8
9	65.8	July, 1912	2	1
10	65.8	October, 1914	2	3
11	64.9	August, 1917	2	10
		Mean	3	0

Colorado, 1888-1919.

No.	°F.	Date.	Interval. Y.	M.
1	42.9	September, 1888	—	—
2	44.0	August, 1891	2	11
3	44.3	July, 1895	3	11
4	44.5	March, 1897	1	8
5	43.0	October, 1898	1	7
5	44.2	January, 1903	4	3
7	44.3	December, 1904	1	11
8	44.2	June, 1906	1	6
9	43.4	November, 1908	2	5
10	41.5	April, 1912	3	5
11	42.0	January, 1917	4	9
			2	10

Minnesota, 1888-1919.

No.	°F.	Date.	Interval. Y.	M.
1	35.4	July, 1890	—	—
2	39.3	March, 1897	6	8
3	39.2	April, 1899	2	1
4	38.2	February, 1904	4	10
5	39.1	May, 1907	3	2
6	39.3	July, 1909	2	2
7	35.5	February, 1913	3	7
8	33.6	November, 1915	2	9
9	31.9	May, 1917	1	6
			3	4

New England, 1888-1919.

No.	°F.	Date.	Interval. Y.	M.
1	44.1	May, 1888	—	—
2	45.8	September, 1890	2	4
3	43.9	April, 1893	2	7
4	45.5	April, 1895	2	0
5	45.8	April, 1899	4	0
6	45.6	June, 1901	2	2
7	45.5	May, 1902	0	11
8	43.2	October, 1903	1	5
9	43.4	June, 1907	3	8
10	45.0	November, 1910	3	5
11	45.0	March, 1912	1	4
12	44.8	July, 1914	2	4
13	42.5	October, 1917	3	3
			2	5

An inspection of the curve shows that these short-period extremes vary from station to station, some being in the nature of principal maxima and minima and the remainder being properly classed as secondary maxima and minima. I have endeavored to distinguish between the two classes of variations and present in the table next below what I take to be the principal maxima and minima with the years of their occurrence.

TABLE 2.—*Dates of principal maxima and minima at the places named.*

	Maxima.	Minima.
Batavia	1877–78	1867
	1888–89	1871–72
	1897	1874
	1906	1880
	1914	1887
	....	1890
	....	1893
	....	1904
	....	1907
Havana	1889	1892
	1893	1894
	1896–97	1901
	1899	1903–4
	1902	1910
	1911–12	....
Arequipa	1900	1903–4
	1902	1909–10
	1906	....
Honolulu	1896–97	1894
	1906–07	1902–3
	1913	1905
	1915	1909

Incidentally, it may be noted that the interval between the occurrence of principal maxima and minima varies anywhere from 2 to 11 years, and also varies from station to station, the interval maximum to maximum at Batavia being considerably longer than at the remaining stations. If we take all of the maxima and minima into account, then, as before stated, the average interval for the maxima is 41 months and that of the minima 37 months. It may be seen from the above table that there is some evidence of world-wide variations in temperature which, obviously, can not be due to the local or secondary circulation; thus we see that a maximum of temperature was experienced at both Batavia and Habana in 1889 and 1897; in Batavia, Habana, and Honolulu in 1897; also in Batavia, Arequipa, and Honolulu in 1906. For the maximum at Arequipa in 1906 see the curve in figure 1.

The synchronism in the minima is not so good although there are sone interesting correspondences.

The records from these four stations prove conclusively, I think, that the temperature in the Tropics is never at rest, but is constantly in oscillation, up and down. The amplitude of the oscillations is small, probably on the average scarcely appreciable to the senses, but nevertheless clearly apparent in the statistics.

Whether these oscillations are simply the systematic deviations of the temperature, due possibly to the local environment, variations in the local and general circulation, or possibly to variations in the insolation which may be superposed upon the effects produced by terrestrial causes is still an open question.

The relation between the progressive changes of temperature in the Tropics and the Temperate Zones is most readily shown by plotting parallel curves representing the two regions. This has been done, but it is impracticable to reproduce the curves for the several portions of the United States. I shall first consider the border region between the North Temperate Zone and the Tropics, as represented by the State of Louisiana, which, it may be remembered, is embraced between the parallels of 30° to 33° North latitude, and the meridians of 90° to 94° West longitude. In making the comparison the permanent climatic differences between the two regions should be kept in mind. Louisiana, while its temperature is to some extent modified by the proximity of the Gulf of Mexico, nevertheless is subject to the full sweep of cold northerly winds which depress the temperature to a degree never reached in Habana. There is, however, a greater similarity between the two curves than was expected, particularly in the larger changes. The synchronism of the epochs of maximum temperatures in the two regions is remarkably good, but there are occasions when the Louisiana maximum follows that of Habana by a few months and there is but a single case, viz, that of 1906, when a maximum in one region is not associated with a corresponding maximum in the other.

It is interesting to note that the principal maximum of the whole term of years in Habana occurred in 1912 and in Louisiana in 1911, although the belief is expressed that the two maxima were due to one and the same cause. The high temperature at Habana was continued some months longer than in Louisiana, thus indicating that the cause of the high temperature, whatever it may have been, ceased to function in Louisiana first. The temperature in the last named began to fall about nine months earlier than in Cuba. The synchronism in the epochs of minima is equally good. One would think that the minimum would occur in Louisiana a little earlier than in Habana, but this is not always the case. For example, the low point for 1903 was reached about the same time in both regions. This was followed by a slight recovery and then a second depression in the spring of 1904, which in turn was followed by a small recovery and then by a third depression in the autumn of 1904, all of which is clearly apparent from a study of the curves of the two regions. The decided minimum of 1910 in Habana—the greatest of the entire term of years—occurred in Louisiana somewhat earlier and the recovery also set in earlier than in Habana. Comparison of the curves for the years 1908–9 is difficult owing to the very sharp contrasts in temperature shown by the Louisiana curve for those years. Finally, we may observe that the severe cold of 1917 penetrated to both Louisiana and Cuba, being plainly perceptible in both curves. This is the most decisive evidence that has been thus far adduced to show that the influence of the secondary circulation penetrates so far south as the latitude of Habana. Having shown that, in general, there is good synchronism in the epochs of maximum and minimum temperature for Habana, a tropical station, and Louisiana, a region outside but near to the Tropics, we will next consider the synchronism of Louisiana and the States of more northern latitude.

Synchronism of Louisiana maxima and minima with those of other States.—The dates of occurrence of maxima and minima as given in Tables 1 and 1a refer to the 12-month consecutive mean whose middle date falls upon the first of the month named; for example, the maximum of June, 1890, for Louisiana refers to the 12-month period beginning with December, 1889, and ending with November, 1890. The maximum in this case is due wholly to high winter temperatures, which in the computation of 12-month consecutive means throws the peak of the maximum in June. It is obvious that the maximum or minimum in any 12-month period may be due to monthly abnormalities spread over but a single month or several months. Two months—one with a pronounced positive departure, the other with an equally pronounced negative departure—will not offset each other in the 12-month consecutive means as would be the case if they were used in the computation of a mean of the 12 calendar months. The response of the temperature in Louisiana to changes brought about by changes in the secondary circulation is not so great in that State as in the other States considered, although by no means is that influence negligible. In the cold season the mean temperature of the State as a whole may be depressed as much as 8° to 10° F. by reason of the prevalence of cold northerly winds, and, on the other hand, when southerly winds are more frequent than usual the temperature is elevated by the same amount. It happens, therefore, that the character of the Louisiana curve is almost entirely that given by the variations of the winter season. Responding to the suggestion that perhaps a consideration of the variations during the summer months might yield important results, I have computed the anomalies of the months of June, July, and August for the term of years available. As might be expected, these anomalies are much smaller than those of the winter, rarely exceeding ±3.5° F. The summers of 1891, 1892, 1894, 1903, 1908, 1913, and 1917 were cool, while those of 1890, 1895, 1896, 1900, 1902, 1906, 1907, 1909, 1910, 1911, 1912, 1915, and 1919 were warm. The tendency, therefore, during the period considered was toward higher temperature, there being a total of 13 warm summers and only 7 cool ones.

In general, the maxima and the minima of the Louisiana curve are not congruent with those of the more northern States, owing doubtless to the fact that the variations in the latter are more directly due to changes in the secondary circulation. The lack of accord in the dates of the maxima and the minima and in the length of the interval between them is clearly shown by the data of Table 1a. The average interval between the maxima for Louisiana and Minnesota is exactly the same, but the individual lengths are all different; hence, for the purpose of forecasting, the averages are useless.

The extent to which the temperature oscillations of the more northern States are damped by changes in an opposite sense due to the influence of the secondary circulation is easily seen. For example, the curves of Washington, Colorado, and New England during the years 1896–97, and for a few years previous thereto, show that the march of temperature was characterized by alternating periods of high temperature and low temperature occurring without order or system. Following the 1896–97 maximum, not only in Louisiana, but elsewhere in the United States, a world-wide depression in the temperature set in. It was first manifest in the United States in the northern and middle Pacific Coast States, the plateau and Rocky Mountain regions in the autumn and early winter of 1898, continuing more or less intermittently until well into 1899.

It was also manifest in northern Europe, northwest Russia and east Siberia, and in a less degree in the East Indies. While the depression in the northern parts of the Temperate Zone may be referred to the influence of the secondary circulation, we can not explain the fall in temperature at Batavia in that manner. The sun-spot curve at that time was descending to the minimum of 1901.

At this point I wish to introduce some evidence bearing upon the systematic deviations of the temperature from the normal in any set of years taken at random aside from those coincident with years of sun-spot maxima or minima. As I have previously pointed out, the march of the temperature in all parts of the globe is characterized by variations up and down from the normal. In the Tropics these variations may be due to variations in the cloudiness, the strength, and possibly a slight change in the direction of the periodic winds due to displacement or readjustment of the pressure distribution in the so-called centers of action in the atmosphere. This evidence is simply a statement showing the deviations of the annual mean temperature for that portion of the globe between 20° South latitude and 60° North latitude for the years 1910, 1911, and 1912. The presentation of these data is possible through the publication of the Réseau Mondial by the British Meteorological Office. The data are given in the table next following (Table 3). Attention is directed to the columns headed "Mean Temperature, Departures in °C."

TABLE 3.—*World departures of temperature and precipitation, 60° North to 20° South latitude, 1910, 1911, and 1912.*

Zone No.	Latitude.	No. of stations.	1910		1911		1912	
			Mean departure.		Mean departure.		Mean departure.	
			Temp.	Precip.	Temp.	Precip.	Temp.	Precip.
			°C.	mm.	°C.	mm.	°C.	mm.
10 Tropics	20° to 10° South	16	−0.10	+256	−0.06	− 13	+0.40	− 60
9 Tropics	10° to 0°	11	±0.00	− 35	−0.01	−258	+0.30	− 16
8 Tropics	0° to 10° North	18	−0.30	− 21	−0.06	−136	+0.40	−280
7 Tropics	10° to 20° North	25	−0.20	+ 26	−0.04	+128	+0.20	− 96
6 Extra Trop	20° to 30° North	27	−0.30	+ 51	±0.00	+ 69	+0.10	+ 41
5 Extra Trop	30° to 40° North, W. half	19	+0.30	−159	+0.20	− 52	−0.30	− 41
5 Extra Trop	30° to 40° North, E. half	24	−0.30	+ 59	+0.30	+100	−0.10	− 10
4 Extra Trop	40° to 50° North, W. half	17	+1.00	− 67	+0.10	− 53	−0.20	− 10
4 Extra Trop	40° to 50° North, E. half	20	+0.70	+ 66	+0.10	+ 15	−0.20	+ 88
3 Extra Trop	50° to 60° North, W. half	11	+0.70	− 20	−1.10	− 74	−0.20	+ 3
3 Extra Trop	50° to 60° North, E. half	25	+1.10	+ 34	+0.90	− 18	−0.60	+ 74

The annual deviations of temperature for each of the years given are of the same order of magnitude as those heretofore found and assigned to the sun-spot influence, thus indicating, it seems to me, that in the ordinary run of years those not characterized by any unusual variation in the number or area of spots the annual deviations in the mean annual temperature may be sufficiently uniform and of a magnitude that will satisfy the requirements of the theory of sun-spot control. A greater number of years of observations will of course, afford conclusive evidence on this point. The concluding section of this paper will be devoted to a review of the literature and evidence thus far available bearing upon the relation between sun spots and terrestrial temperature.

SUN-SPOTS AND TERRESTRIAL TEMPERATURE.

It is generally agreed that the variations in the mean annual temperature, in the Tropics especially, run parallel with variations in the spottedness of the sun. It may also be considered as definitely established that the amplitude of the variations is small, on the average less than 1° C., and that it diminishes with distance from the Equator. It is further established that the heat maximum at the Equator corresponds to the minimum of sun spots and that the heat minimum corresponds to the maximum of spots. On the other hand, as everyone who has investigated the subject knows, there is at times a decided lack of synchronism in the occurrence of the phenomena; for example, if variations in sun spots are the cause of variations in terrestrial temperature, that is to say, if the two events stand in the relation of cause and effect, then the one should precede the other or at least be coincident therewith. Koppen [1] finds that the heat maximum of the Tropics precedes the spot minimum by nine-tenths of a year on the average and that the interval increases with distance toward the poles. The temperature minimum at the Equator, however, coincides rather closely with the occurrence of the spot maximum. Newcomb [2] found a little closer synchronism but yet not so good as might be wished.

The sun-spot period itself, commonly accepted as being 11.2 years in length on the average, varies irregularly from, say, 9.6 to 12.7 years, counting from minimum to minimum, and this adds another complication to the problem. Köppen in his discussion takes cognizance of this changing length of the period and has corrected the average terrestrial temperatures accordingly. Mielke [3] following Köppen, likewise makes a correction in terrestrial temperatures on account of the varying length of the sun-spot period.

The usual method of showing the parallelism of the phenomena is that of plotting the annual variation of the two events on coordinate paper and noting the agreements and disagreements. It is safe to say that anyone who sets out to show a parallelism will find sufficient resemblance, the one curve to the other, to lead him to the belief that a real relation subsists. I think that it is also true that, in general, the investigator is apt to slur over or disregard entirely the lack of parallelism which in my experience is at times as pronounced as is the resemblance of the two curves. There is also to be noted an apparent disinclination to investigate closely those cases of maxima and minima of temperature which are not in accord with the theory of solar origin through sun spots.

Difficulty of disentangling the sun-spot influence from that of the general and secondary circulation.—One need have but a short experience with the daily weather maps of the cold season in Temperate Zones to discover how tremendously important as a temperature control is the secondary atmospheric circulation. The outstanding features of this control are: (1) It is apparently both ephemeral and fortuitous, the cyclone serving to elevate the temperature during a period of not to exceed a day or so, over an area that may range in extent from a few thousand square miles to the size of one third of the North American Continent, and the anticyclone in turn serving to depress the temperature by the same amount over an equal area; (2) while terrestrial temperature is primarily controlled by the output of solar energy, the immediate control which results in the day to day variations is largely the result of horizontal convection whereby warm air is transferred from lower to higher latitudes and cold air from higher to lower latitudes.

[1] Met. Zeit., VIII: 241-248; XV: 279-283; XXXI: 140-150.
[2] Newcomb, S., Trans. Amer. Phil. Soc., XVI.
[3] Mielke, Joh., Archiv. der Deutschen Seewarte No. 3, 1913.

Variations of temperature are therefore dependent to a large extent upon the frequency and movement in latitude of cyclones and anticyclones. An unusually large number of cyclones moving due eastward in one district may cause the temperature to be higher than usual, while the same number moving in the same direction may cause the opposite temperature conditions in another district; hence at the close of the calendar month, when the balance of temperature is struck, we do not get a true measure of the difference between the incoming heat of insolation and the outgoing loss of heat by radiation, but rather we obtain a residual, the magnitude of which depends upon the activity of the latitudinal convective interchange of the month and the geographic position of the station.

As a general theorem it may be postulated that the quantities of heat received by insolation and those lost by radiation in the course of the year on the average are equal, for were it not so there would be progressive warming or cooling of the atmosphere and the earth, as the case might be.

The observational material as regards terrestrial temperature does not show permanent warming or cooling to have occurred in any part of the globe. The observations do show, however, that progressive warming and cooling through short cycles is the rule, more especially in Temperate Zones, although the phenomenon is not confined to any one part of the globe to the exclusion of the remainder. There may be as many as three separate and distinct cycles of progressive change to warmer or to cooler within one sun-spot cycle; if now one of these short-period changes should coincide with the epoch of maximum or minimum of sun spots, it would naturally result in an intensification of the terrestrial temperature extremes at that time and therefore would be considered by the proponents of the theory as abundant justification of the correctness of the theory. The problem therefore resolves itself into a study of the short-period cycles of progressive temperature change from lower to higher levels and vice versa.

Influence of diminished atmospheric transmissibility.—Diminished atmospheric transmissibility must reduce the amount of solar energy received at the earth's surface and in this way serve, in part at least, to lower the temperature of the atmosphere. In his studies on solar radiation, Prof. Kimball has noted that there were marked diminutions in atmospheric transmissibility in the years 1884 to 1886 and in 1903 to 1904, that were undoubtedly connected with violent volcanic eruptions[1] and that in 1891 and 1907 less marked diminutions occurred which have not been connected with phenomena of volcanism. Since the above dates do not coincide with the epochs of sun-spot maximum or sun-spot minimum it will be of interest to see whether there is a lowering of the temperature on the years in question. The temperature at Batavia was depressed in each case except that of 1891, when there was a pronounced maximum. There was a very general depression of the temperature in 1903–4 in various parts of the world, particularly in the Tropics. The curves for Batavia, Havana, and Arequipa show the depression very distinctly, but the Honolulu curve shows a maximum

[1] Kimball, H. H., Solar Radiation, *Bul., Mt. Wea., Obsy.*, 1910, vol. 3, p. 117.

instead of a minimum. The curves for the five different portions of the United States show confirmatory as well as conflicting evidence of the reality of a fall in temperature being caused by diminished atmospheric transmissibility for solar radiation and less diminished for earth radiation. As has been previously shown in this paper, a cycle of temperature change from minimum to minimum is completed in about three years, the time being slightly longer in the Tropics than in Temperate Zones and being longer in some parts of temperate zones than in other parts. The latter fact, coupled with the additional fact that the short-pariod temperature oscillations are soonest completed in those regions which come most directly under the control of the secondary circulation, seems to tie up the occurrence of these short-period variations with terrestrial causes.

If the causes were extra-terrestrial then it should be expected that there would be greater uniformity in the various parts of the globe.

Monthly temperature variations for two districts in the United States.—The monthly variation in temperature, above and below the normal, afford the most convenient material available for study. I will now consider the mean annual departure for two districts in the United States, first, the Northern Plateau, comprising within its boundaries the eastern portion of the States of Washington and Oregon and all of Idaho. The second region is that of the Lower Great Lakes. I have compiled from Table 1 of the MONTHLY WEATHER REVIEW the monthly departures of mean temperature for these two districts for the years 1916, 1917, and 1918 separately, and present the smoothed means in Table 4 below. The smoothing was accomplished by the formula $\frac{(a+2b+c)}{4}$. The means have been plotted to form the curves of text figure 2.

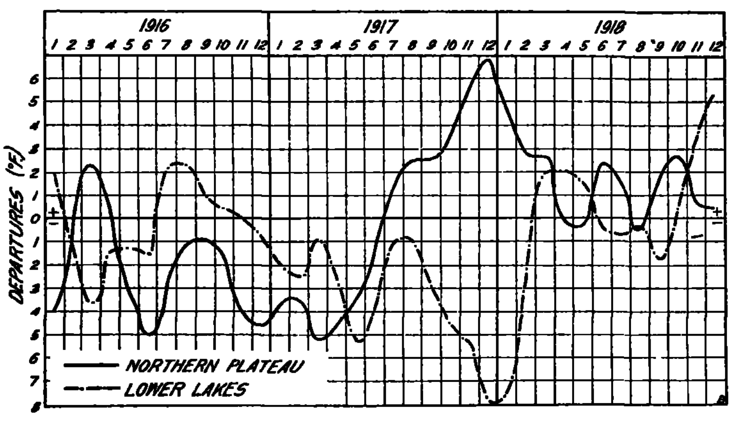


FIG. 2.—The monthly and annual march of the temperature in the region of the Lower Lakes and the Northern Plateau during 1916–1918.

TABLE 4.—*Monthly mean temperature departures (smoothed) for the Northern Plateau and the Lower Lakes, respectively (°F).*

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	Northern Plateau.											
1916.....	4.0	0.4	2.4	0.0	3.2	5.0	2.3	1.0	0.8	2.0	4.0	4.8
1917.....	3.7	3.6	5.2	4.7	3.4	1.6	1.5	2.6	2.5	3.2	5.4	......
1918.....	4.8	2.8	2.8	0.1	0.2	2.5	1.4	0.5	1.8	2.8	0.8	0.6
	Lower Lakes.											
1916.....	2.2	1.8	3.8	1.3	1.2	1.3	2.2	2.4	0.9	0.4	0.0	0.8
1917.....	2.0	2.4	0.9	2.4	5.2	3.7	1.0	0.8	3.1	4.7	5.4	7.9
1918.....	7.5	1.6	2.0	2.0	1.5	0.6	0.7	0.4	1.8	0.3	3.5	5.2

Positive departures are given in full-face type; negatives, in ordinary type.

Considering the curves of fig. 2 for the Northern Plateau, this district being represented by observing stations at Baker City, Oreg., Boise, Lewiston, and Pocatello, Idaho; and Spokane and Walla Walla, Wash., it is at once observed that the temperature rose from a low value in January, 1916, to a point 2.4° F. above normal in April, then fell to 5° below the June normal, rose again to a point within 0.8° of the normal in September and then again descended to a point 4.8° below the normal in December. During the year 1916 there were therefore two each distinct rises and falls in temperature, each one being accomplished in about three months. The march of the temperature for the lower Lake region, the dashed curve, is similar in some respects and different in others. Starting at a point 2° F. above normal in January, the course is downward instead of upward, as in the case of the Plateau. For the three months at the beginning of the year the march of the temperature in the two regions is in an opposite sense; beginning in June, however, the temperature begins to rise in both regions and rises about the same amount in both. In the Plateau region the temperature at the beginning of the rise was depressed below the normal a greater amount than in the Lake region and as a consequence the latter passed to a point about 2° above the normal while the former did not reach the normal.

A fall in temperature then sets in, which reached a maximum in the Plateau region in December and in the Lake region in the following February. In each case there was a short recovery followed by a second depression. Note here that the oscillations are now out of step by two months.

Beginning on the Plateau in March, 1917, temperature began to moderate and continued its upward trend until the following December, when it had reached a point about 7° F. above the normal for that time of year. Meantime the temperature in the Lake region was falling at about the same rate that it was rising on the Plateau. The greatest depression, almost 8° below normal, was reached in December, 1917. In both cases the results noted were general rather than local, high temperatures prevailing over the whole of the Plateau and Pacific coast regions and it was generally cold east of the Rocky Mountains. Curiously enough the previous month of November, 1917, had been unusually warm west of the Mississippi. In North Dakota it was the warmest November in 25 years.

The obvious explanation is that in the warm month of November, 1917, the pressure distribution gave southerly winds over large areas. If these winds had persisted for only a few hours their effect would have been lost in the monthly means, but persisting as they did for days at a time the effect upon the monthly means remains for all time. In November, 1917, the warm month, the centers of anticyclones followed two fairly well marked routes, viz, (1) eastward from the Pacific across the States of Washington, Oregon, Idaho, and Montana, and thence southeastward toward the Gulf of Mexico, and (2) east-southeast from about north latitude 55°, west longitude 100°, to the Great Lakes and passing thence east-southeast from the north of the Lakes to the Atlantic States.

In the cold month of December, 1917, the centers of anticyclones were concentrated in one main group, which entered the United States from the Canadian northwest by way of the Missouri Valley, which they followed until the middle Mississippi Valley was reached. From that point there was more or less spreading of the paths, some leading directly to the east and others to the Gulf of Mexico. There was this characteristic difference, viz, a *much greater southerly component of motion in the paths of anticyclones than in the warm month.*

The foregoing is but a single example from many that could be given to show that the temperature control, in temperate regions at least, rests largely with the secondary circulation. There are, of course, other features of the local weather conditions that contribute largely to the magnitude of the observed temperature anomalies, as, for example, the presence or absence of clouds, the presence of absence of a snow cover. Moreover, orographic barriers serve to accentuate and localize climatic differences; thus in a sense the large differences in temperature between the northern Plateau and the region of the Great Lakes previously described were due to the presence of the Rocky Mountains. In the one case, December, 1917, the movement of cold air from north to south took place along and to the east of the Rocky Mountains, while in the other case, November, 1917, the air movement was almost wholly from the WSW. After crossing the mountains it was warmed by the descent to lower levels, and the skies became clear, thus permitting unhindered insolation. The percentage of clear sky—sunrise to sunset—in November, 1917, the warm month, was as high as 80 per cent in eastern Montana, while for the same place in December, 1917, it sank to 20 per cent.

In the last-named month the cold was doubtless intensified by a great snow blanket which overspread the entire area north of latitude 35°; in the Ohio Valley and the Lake region the snow cover lasted well into February of the succeeding year. It may well be that this great snow blanket was itself a factor in perpetuating and possibly intensifying anticyclonic conditions, once these were established, as in the cold winter of 1917–18. In this connection see the account thereof by Mr. Day in the MONTHLY WEATHER REVIEW, December, 1918, **46**:570.

The foregoing paragraphs illustrate the lack of uniformity with respect to the progressive changes of temperature in two not-widely separated regions, the partial control by climatic barriers, and especially the dominant control of the secondary circulation at all times.

Annual temperature variations during three sun-spot cycles for United States as a whole.—I have computed the mean deviation of the temperature from the normal for the United States as a whole for each year from 1886 to 1919, both inclusive, and present the actual and the smoothed means in Table 5, next below. The smoothed deviations have been plotted to form the lower curve in figure 3. The curve at the top of this figure represents the smoothed sun-spot numbers of Wolfer divided by 10 in order to bring them within a magnitude suitable for plotting.

In general, there is good correspondence between the sun-spot curve (if the reader will mentally invert it the agreement may seem clearer) and the curve showing deviations of temperature from the normal. The spot minima of 1889.6 and 1901.7 are both associated with an appreciable rise in the temperature. There is also a distinct lowering of the temperature roughly synchronous with the spot maxima of 1883.9, 1894.1, and 1917.7. The most discordant result is the failure of the temperature to reach a maximum in 1913.7. It will be noticed that had not there been a drop in the temperature in 1912 there would probably have been a maximum in 1913.

TABLE 5.—*Annual departure of temperature from the normal for the United States as a whole, computed from district departures (in °F.).*

Years.	Departures. Actual.	Departures. Smoothed.	Years.	Departures. Actual.	Departures. Smoothed.	Years.	Departures. Actual.	Departures. Smoothed.
1886...	−0.6	−0.1	1898...	0.5	0.3	1909...	0.2	0.5
1887...	0.1	−0.2	1899...	0.0	0.5	1910...	0.9	0.7
1888...	−0.4	0.0	1900...	1.6	0.9	1911...	0.9	0.5
1889...	0.7	0.4	1901...	0.6	0.8	1912...	−0.6	0.1
1890...	0.7	0.5	1902...	0.4	0.3	1913...	0.7	0.3
1891...	0.1	0.1	1903...	−0.2	0.0	1914...	0.6	0.6
1892...	−0.5	−0.4	1904...	−0.1	−0.1	1915...	0.5	0.2
1893...	−0.9	−0.4	1905...	−0.1	0.1	1916...	−0.2	−0.2
1894...	0.6	−0.1	1906...	0.6	0.3	1917...	−0.9	−0.4
1895...	−0.8	−0.1	1907...	0.2	0.4	1918...	0.7	0.3
1896...	0.6	0.2	1908...	0.8	0.5	1919...	0.6	0.7
1897...	0.3	0.4						

Positive departures are given in **full-face type**; negative in ordinary type.

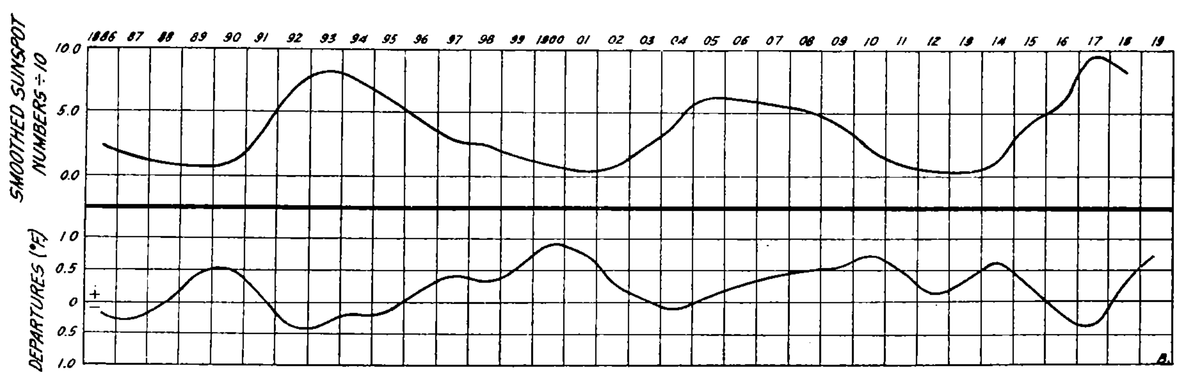


FIG. 3.—Smoothed temperature departures, United States as a whole, compared with smoothed sun-spot numbers, 1886–1919.

It has been suggested that the lowering of temperature in 1912 at a time when the normal expectation was for rising temperature may have been due to diminished atmospheric transmissibility, which in turn was conditioned in part, at least, upon the prevalence of dust in the higher levels of the atmosphere.[1]

It must be admitted that except for the dip in the temperature in 1912 there is good parallelism between the two curves if we invert the sun-spot curve. It seems to be highly important to examine closely the world-wide temperature distribution of 1912. To do this we have but to refer back to Table 3.

This table shows that for 1912 there was a pronounced excess in the temperature of the Tropics, a smaller excess in the zone between 20° and 30° North latitude, and thence northward to 60° N. the temperature was below the normal, in the eastern half of the zone, amounting to 0.6° C. As has been previously observed the absolute maximum of the entire term of years at Habana was reached in 1912 and the absolute maximum in Louisiana

[1] Kimball, Prof. H. H., *Bulletin Mount Weather Observatory*, 1912, 5:161; Mo. WEATHER REV., Jan., 1913, 41:153.

was reached the year previous. Referring to the record of this year (1911) it is found that the variations in the Tropics were small and negative, that in the zone between 20° and 30° North the temperature was normal and that it was above normal in all zones farther north except that one between 50° and 60° North latitude. It thus appears that the zonal distribution of high temperature was disturbed more or less locally in 1911 by low temperatures, especially in the Canadian northwest, and that the distribution over Europe was even more irregular, as may be seen from Table 3.

Examining, now, the temperature curves for New England, Minnesota, etc., it will be noted that a pronounced depression of the temperature occurred in the year 1911 in three out of the five districts, beginning first in Minnesota and being followed by Colorado and last by Louisiana. This may be interpreted somewhat as follows: In 1911 at a time when world-wide temperatures were rising and the temperature in the United States had been continuously above the normal for six consecutive years, there set in, at first, locally and not absolutely unbroken a swing of the temperature toward the other extreme. The change in the United States was first noted in the north Pacific Coast States for January, 1911. In the following month it had overspread the whole of the Pacific Coast States and the Plateau region west of the Rocky Mountains and subnormal temperature continued over this entire region also in April, May, and June. The first half of the year also showed temperature below the normal in Atlantic Coast States, beginning in New England in February and overspreading the middle and south Atlantic States during March and April. Apparently this eastern depression of the temperature was entirely independent of the western depression. The latter persisted practically throughout the year with a culmination of the cold in November, in which month the temperature was consistently below the normal except in the Florida peninsula and in southern California. Since those regions are the most remote from the influence of the secondary circulation, this exception is easily understood. The evidence of the year 1911 does not support the idea that there is a progressive spreading of the abnormalities of temperature from one region to another regardless of orographic barriers, but rather that the spread is from north to south within the climatic province.

It may be accepted as a fundamental proposition that relatively long-continued high temperature is provocative of a change to the other extreme; in other words, that the tendency is always toward the normal. There are, of course, important exceptions to the rule, as when high temperature and droughty conditions prevail for several months, but in general the rule holds. As a forecasting precept it is utterly useless because there is no way of telling in advance when the abnormally warm period will come to an end.

The mechanism whereby the change from higher to lower temperature is brought about is evidently through the pressure. For some reason not yet clearly perceived the leakage of cold air from higher to lower latitudes is greater and more easily accomplished in some years than in others, and it is said of those years in which the leakage is great that it is due to an intensification of the great continental anticyclone that overspreaks the continent of North America to the northwest of Hudson Bay. All of this is perfectly true, yet we are still no nearer to a solution of the problem.

The idea that there is a sort of compensation in the annual temperature distribution, some regions having positive anomalies which are offset by negative anomalies in other parts of the globe, has not much support. It can be shown that there are years of general high temperature in all parts of the globe, there are others that are generally cold, and still others in which the areas of positive and negative departures are almost equal to each other. Although some compensation may appear in the last case, there is no known means of proving that supposition. It has been shown in this discussion, moreover, that a temperature distribution of exactly the opposite character may prevail in two not widely separated regions. It is the universal experience in those regions where the temperature distribution is best known, that a mixed distribution—some regions positive and some negative—is the most probable one, and also that as the size of the area increases the less is the probability that the temperature will be, without exception, above or below the normal over the entire area. It seems logical, therefore, to assert that the same rule must apply when world-wide temperature distribution is considered and that only at wide intervals should we expect complete and definite evidence of the effect of some cosmical cause.

It is useless to look in the Temperate Zones for evidence of changes that may be due to extra-terrestrial sources. What, therefore, is most needed at the present moment is a critical analysis of existing temperature observations in the Tropics; the long series should be reduced to a perfectly homogeneous series and a few more first-class observatories should be established in both hemispheres near the Equator.

CONCLUSIONS.

(1) The mean temperature, whether of a week, a month, one or more years, is in practically continuous oscillation up and down of varying magnitude and duration. These oscillations are often concurrent over large areas of the earth's surface; they may or may not be in the same sense.

(2) Attempts to discover the length of the period of oscillation have generally shown that the oscillations occur and recur, apparently without order or in any systematic way. The bulk of the evidence points to a period of between three and four years, or the third of a sun-spot cycle, as being that the most commonly experienced.

THE SUN-SPOT CYCLE.

(3) It is generally recognized that changes in the annual mean temperature in the Tropics run parallel with changes in the spottedness of the sun; that the heat maximum in the Tropics is associated with the epoch of spot minimum and that the temperature minimum is associated with the epoch of spot maximum. There is, however, a lack of synchronism in the variations in sun spots and terrestrial temperatures which suggests that the two events may not stand in the relation of cause and effect but that both events may be due to a common, at present unknown, cause.

(4) The temperature variations in the United States, east of the Rocky Mountains and above North Latitude 40° are so directly controlled by the secondary circulation as to render futile any attempt to forecast the character of the season in advance. On the Pacific coast and in the zone south of North Latitude 40° the outlook is more hopeful.

(5) The amplitude of the variations in terrestrial temperature that may be due to sun-spots is small, less than 1° C. on the average in the Tropics and diminishing thence toward the poles. In the United States, as shown in Table 4, the range from the year of highest temperature at sun-spot minimum, 1900, to the year of lowest temperature in a year of spot maximum, 1917, amounted to 2.5° F., 1.4° C.